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ADVANCED MATERIALS FOR SPACE

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SPACE MATERIALS PROGRAM

The resources for the space materials program at Langley during FY-79 were provided by LSST and by NASA's Base R&T program. Funds from both sources were used to fund two major contracts to assess the radiation stability of current composites. These contractual efforts represent the bulk of the materials program and are directed at the space durability of composites which is considered to be the principal uncertainty associated with the long term (25-30 years) use of composites in thin-gage minimum weight large space structures. In general, the long-term basic issues are being addressed in the Base R&T program while the more near-term systems oriented tasks are being worked as part of the LSST program. The goal of the base R&T program is to determine radiation damage mechanisms of resin matrix composites and formulate new polymer matrices that are inherently more stable in the space environment. New composites will be manufactured with these improved resins to develop a class of composites optimized for long term use in the space environment.

The principal thrust of the LSST program is to develop the materials technology required for confident design of large space systems such as antennas and platforms. Areas of research in the FY-79 program include evaluation of polysulfones, measurement of the coefficient of thermal expansion of low expansion composite laminates, thermal cycling effects, and cable technology. The development of new long life thermal control coatings and adhesives for use in space will be included in the LSST materials program next year.

SPACE MATERIALS PROGRAM

BASE R & T

- o RADIATION STABILITY OF COMPOSITES
  - o ABSORBED DOSE EFFECTS
  - o EQUIVALENCE OF e^-, p^+, γ
  - o COMBINED EFFECTS
  - o INSITU TEST REQUIREMENTS
  - o POLYMER CHEMISTRY
  - o DOSE / DEPTH PROFILE ANALYSIS
  - o IN-HOUSE RADIATION CAPABILITY
- o THERMAL CONTROL COATINGS
  - o WHITE PAINT COATINGS
  - o VAPOR DEPOSITED METALS
- o HIGH DIMENSIONAL STABILITY COMPOSITES
  - o Gr / Mg - PR[illegible]ERTY CHARACTERIZATION
  - o Gr / GLASS - [illegible]TERIALS DEVELOPMENT
  - o SiC / Ti - SEL[illegible]IVE REINFORCEMENT
- o INDUCTION WELDING OF COMPOSITES

LSST MATERIALS

- o CABLES
  - o MECHANICAL / PHYSICAL PROPERTIES
  - o MECHANICAL CREEP
  - o ENVIRONMENTAL EFFECTS
  - o PACKAGING AND DEPLOYMENT
- o DIMENSIONAL STABILITY
  - o CTE MEASUREMENT TECHNIQUES
  - o ENVIRONMENTAL EFFECTS
  - o PROCESSING VARIABLES
  - o LAMINATE ANALYSIS
  - o THERMAL FATIGUE OF JOINTS
  - o THERMAL CONTROL

Figure 1

LSST MATERIALS PROGRAM

The activities currently included in the LSST materials program at Langley are shown in figure 2. The program began in FY-78 and will be completed during the first quarter of FY-83. The areas being addressed in FY-80 include cables and dimensional stability of composites. These activities are projected to continue through FY-82 yielding the expected results shown on the right hand side of figure 2. The activities associated with the space durability of composites are largely contractual and will be completed during FY-80 and 81. Space durability research will continue past FY-80 but will be funded through Langley's Base R&T program rather than through LSST. Consideration is being given to including research on metal matrix composites and composite joints in the LSST materials program.

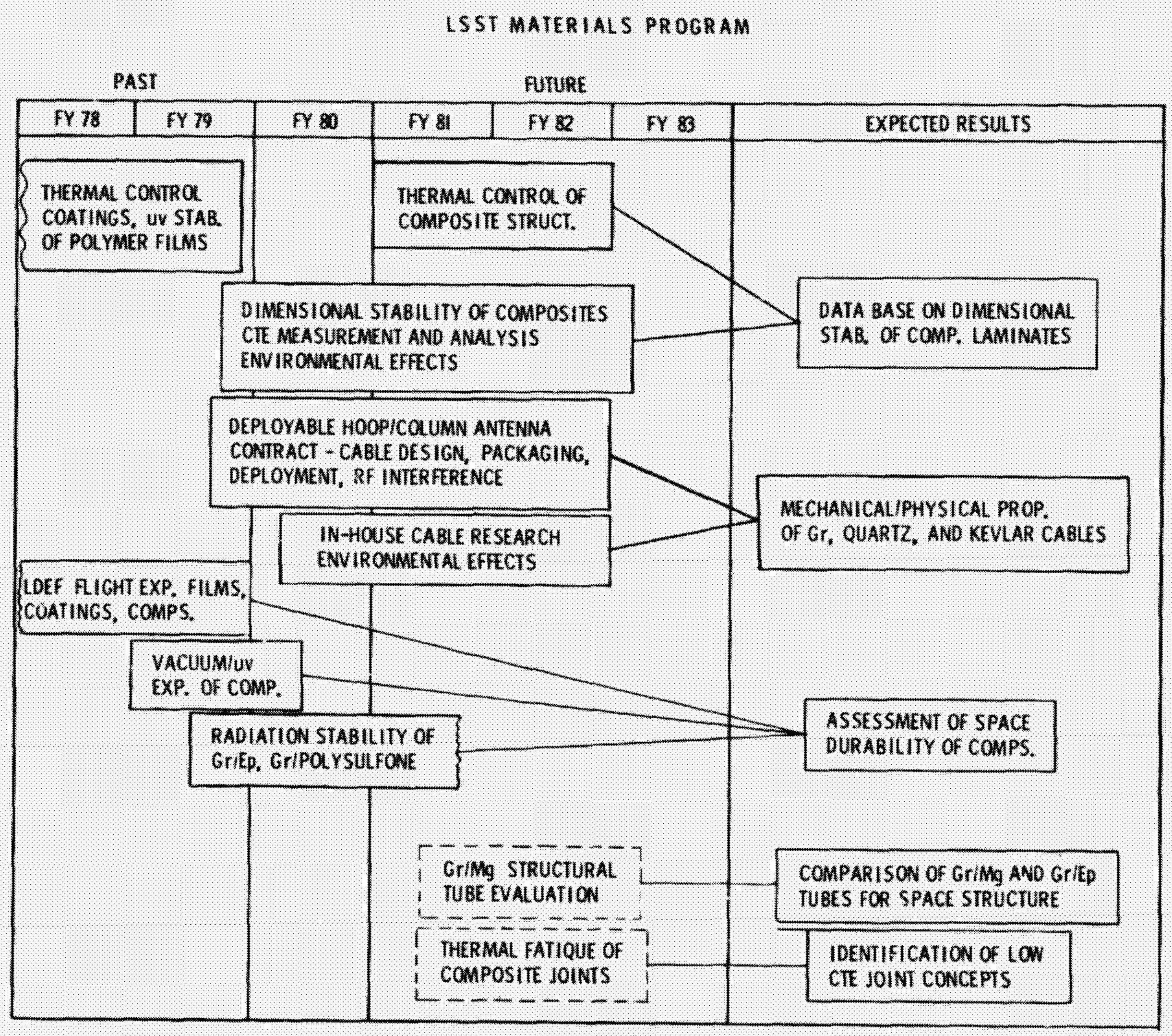


Figure 2

DURABILITY CONCERN FOR STRUCTURAL COMPOSITES IN SPACE

A composite structural member, designed for space use, is actually a system of components consisting of a thermal control coating, structural adhesive for bonded joints and the composite laminate as indicated in figure 3. Each component has specific properties which must be maintained, with little or no degradation, throughout the use-life of the structure. Optical properties of coatings will be designed to maintain spacecraft temperature within acceptable limits. The coatings will absorb UV, much of the proton flux and the low energy electrons. Coatings which undergo optical changes and/or spallation on exposure to the environment could result in exposure of the underlying composite or result in the temperature limits of the structure being exceeded.

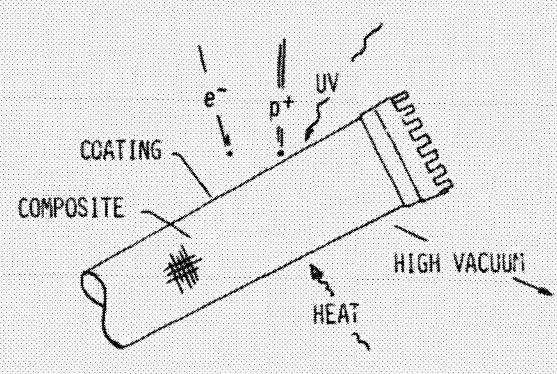
Composites must also maintain acceptable properties through the design life of the structure. The radiation environment however, consisting primarily of high energy electrons, is expected to generate changes in the mechanical and physical properties of the polymeric matrix material because of the relatively high radiation dose level which would be absorbed for long term (10-30 years) missions. Crosslinking and degradation of the polymer matrix are expected to occur. Changes in stiffness, strength, or dimensional stability must therefore be considered in the initial design of the system.

Structural adhesives used for bonded joints should be stable in the space environment.

DURABILITY CONCERNS FOR STRUCTURAL COMPOSITES

DESIRED PROPERTIES OF THERMAL CONTROL COATINGS

- 0 LOW α / ε
- 0 ABSORB UV, p^+, LOW EN. e^-



DESIRED COMPOSITE PROPERTIES

- 0 HIGH STIFFNESS
- 0 HIGH SPECIFIC STRENGTH (TENSION, COMPRESSION, SHEAR)
- 0 GOOD DIMENSIONAL STABILITY (LOW α / K_T)
- 0 LOW MINIMUM GAGE
- 0 HIGH RESISTANCE TO MICROCREEP
- 0 LOW RATE OF OUTGASSING

ENVIRONMENTAL CONCERNS

- 0 COMPOSITE PROPERTY CHANGES
- 0 OPTICAL CHANGES IN COATINGS
- 0 SPALLING OF COATINGS
- 0 SPACECRAFT CHARGING
- 0 LOSS OF LOW MOL. WT. SPECIES
- 0 LOSS OF SHEAR STRENGTH IN ADHESIVE BOND JOINTS

Figure 3

SUMMARY OF IMPORTANT SPACE ENVIRONMENT PARAMETERS

A major factor affecting the selection and utilization of materials for any space application is understanding the service environment and the interaction of this environment with the materials of interest. The key elements of the space environment that are known to affect organic materials and the principal concerns associated with each of the major elements are given in figure 4. This table shows the major parameters, nominal range and reason for interest in each parameter.

The major environmental parameters in the space environment are low pressure (high vacuum), ultraviolet radiation, ionizing radiation (e^- and p^+) and thermal cycling. Other types of radiation exist in space, but are not considered, at this time, to be significant.

Each phase of the space environment can have significant effects upon polymer matrix structural composites. The constant low pressure for example, may cause dimensional changes due to outgassing and microcracking. UV can cause degradation of coatings. High energy electrons may affect both the surface and bulk properties of the composite. High proton flux may degrade thermal control coating efficiency. The combination of these environmental elements acting together on the structural element may also cause combined or synergistic effects. The combination of high vacuum, ionizing radiation and thermal cycling can be a severe test of the materials' ability to perform.

SUMMARY OF IMPORTANT SPACE ENVIRONMENTAL PARAMETERS
AND MATERIALS UNCERTAINTY ASSOCIATED WITH EACH PARAMETERS

ENVIRONMENTAL PARAMETER	NOMINAL RANGE OF PARAMETER	REASON FOR INTEREST IN PARAMETER
VACUUM	PRESSURE 10^{-5}–10^{-13} mPa	VACUUM OUTGASSING RESULTS IN LOSS OF MOISTURE AND SOLVENTS RESULTING IN DIMENSIONAL CHANGES
ULTRAVIOLET	WAVELENGTH 0.1-0.4 μm INTENSITY 1.4 Kw/m^2	DEGRADATION OF COATINGS
PROTONS	ENERGY 0.1-4 MeV FLUX $10^8 p^+/cm^2$-sec	DEGRADATION OF COATINGS AND SURFACE PLIES OF COMPOSITES
ELECTRONS	ENERGY 0.1-4 MeV FLUX $10^8 e^-/cm^2$-sec	SURFACE AND BULK DAMAGE; SPACECRAFT CHARGING
TEMPERATURE CYCLING	MATERIAL TEMP 80 K TO 420 K	MICROCRACKING, THERMAL WARPING, DETERIORATION OF ANTENNA GAIN DUE TO SURFACE DISTORTIONS

Figure 4

ENERGY DEPOSITION FROM THE SPACE RADIATION ENVIRONMENT

To fully understand the effect of space radiation on the properties of composite materials, it is necessary to know where the radiation is absorbed in the composite. Calculations are being conducted to determine the deposited energy density averaged over macroscopic dimensions and thus determine the dose gradients as a function of orbital parameters. This information is useful for selecting exposure conditions for ground based simulations of GEO. Effort is also being directed at trying to find a LEO orbit which would give an absorbed radiation dose similar to that expected for GEO exposure. A long term materials flight experiment in LEO is preferred to one in GEO because of the possibility of periodic Shuttle rendezvous to remove and replace specimens.

Energy deposition on a microscopic scale is also being examined in search of possible anomalous effects due to the proton track structure. The energy distribution over the molecular unit must be known to fully understand radiation damage mechanisms. The source strength of specific chemical precursors will be estimated along with the density of volatile products formed.

ENERGY DEPOSITION FROM THE SPACE RADIATION ENVIRONMENT

- Macroscopic Energy Density as a Function of Orbital Parameters
    1. Determination of energy density gradient
    2. LEO simulation of GEO
    3. Laboratory simulation of GEO
- Microscopic Energy Density Distribution (Relative Electron-Proton Quality)
- Energy Distribution Over Basic Molecular Unit
- Source Strength of Specific Chemical Precursors
- Calculation of Initial Source of Volatile Products

Figure 5

DOSE FOR TYPICAL TRAPPED RADIATIONS IN THREE GEOMETRIES

The dose for typical electron and proton spectra is shown as a function of depth from the surface in the different geometries. The sphere and slab geometries were chosen to bracket the exposure in any other geometry. The cone was taken as a "typical" geometry. Dose gradients will be calcuated using these techniques as a function of orbit parameters to estimate the absorbed dose for long term exposure in the space environment for specific structural elements.

DOSE FOR TYPICAL TRAPPED RADIATIONS IN THREE GEOMETRIES

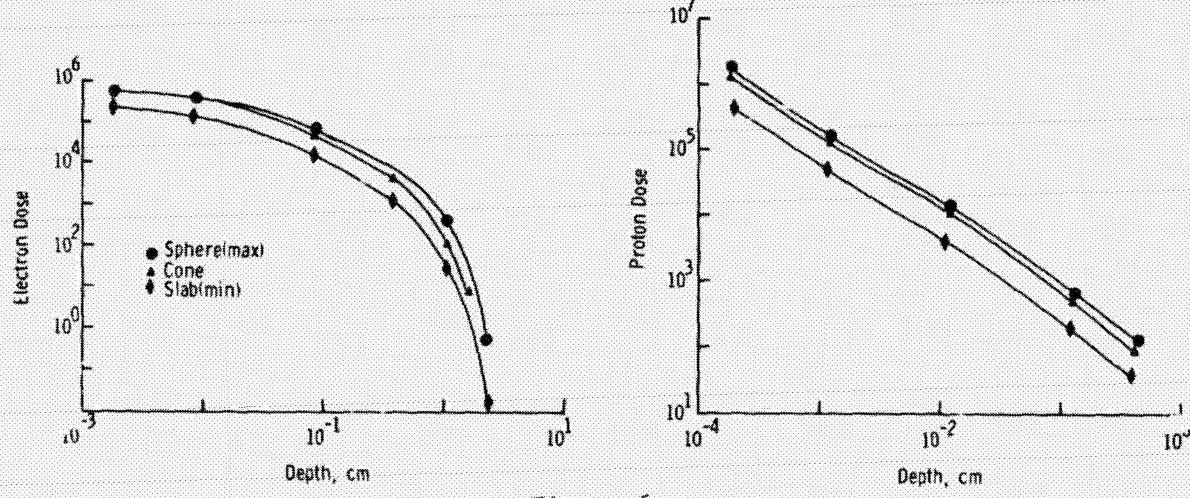


Figure 6

ELECTRON AND PROTON PENETRATION IN CURED NEAT RESIN AND COMPOSITES

Electron and proton penetrations have been determined for a graphite/epoxy composite. The values of penetration were determined from Bethe's stopping power relations for inelastic collisions (excitation and ionization). Figure 7a suggests that the energy absorption profiles for a 4 Mev electron in a composite is not appreciably different from that for a neat resin. Similar conclusions may be made for electrons having different initial energies.

Figure 7b indicates that the penetration of electrons with initial energies between 0.2 and 4.0 Mev is linearly dependent on the energy. The absorption of all the electron's energy, and hence the electron, depends on the electron's initial energy and the material thickness. A resin thickness of 0.05 cm (approximately 4-ply composite) would capture electrons with initial energies less than 0.25 Mev and absorb approximately 0.31 Mev of energy from electrons with initial energies greater than 0.25 Mev. Similarly, resin thickness of 0.25 cm (20 ply composite) would capture electrons with energies less than 0.85 Mev and absorb approximately 0.63 Mev of energy from electrons with energies more than 0.85 Mev. Thus, considerable energy doses would be absorbed by composite materials used in long duration space missions.

Figure 7c is a plot of pathlength of electrons with initial energies between 1 and 2 Kev. Figure 7d is a plot of pathlength of protons with initial energies between 0.5 and 1.75 Mev. Most of the protons in the space environment would be absorbed in a thin layer near the surface.

ELECTRON AND PROTON PENETRATION IN CURED NEAT RESIN AND COMPOSITE

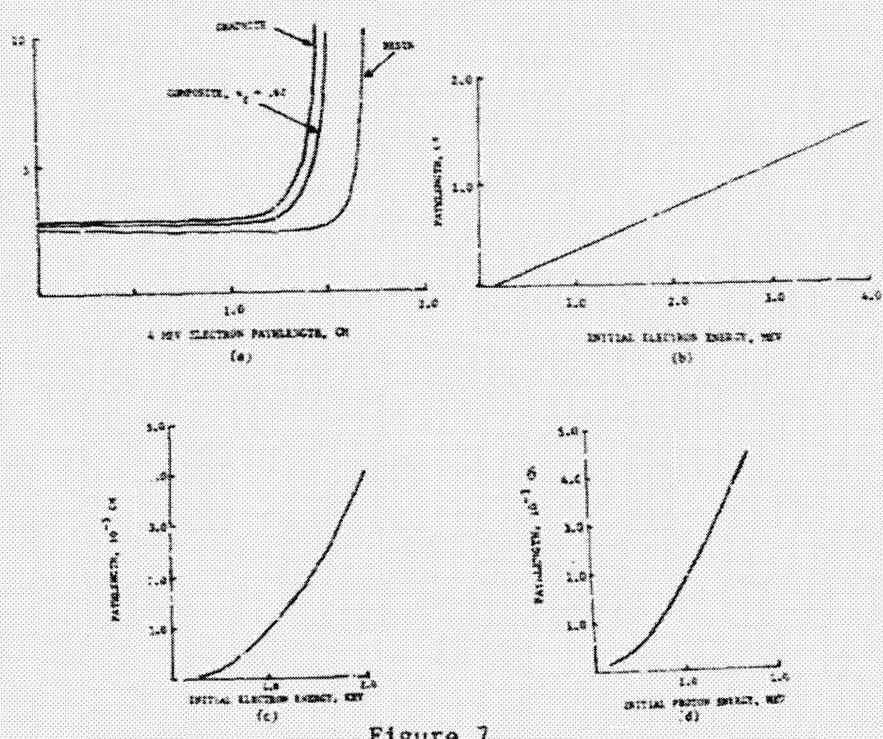


Figure 7

EFFECTS OF ELECTRON AND GAMMA RADIATION ON FLEXURAL PROPERTIES OF COMPOSITES

A study is underway to compare the effects of electron and gamma radiation on the flexural properties of graphite/polymer composites. The electron energy is 0.5 MeV. The gamma source is Cobalt-60. The test specimens are 4-ply unidirectional graphite/polymer composites which measure 2.34 x 1.27 cm. The flexural property measurements are made with a three-point bending fixture. Specimens are predried to remove moisture. For the electron exposures the specimens are inserted in thin-walled metal vacuum bags and remotely inserted into and removed from the electron beam by a conveyer belt system. For the gamma exposures, the fifteen centimeter exposure cell is maintained under vacuum during exposure. The specimens' flexural properties are immediately tested upon completion of exposure. Flexural property testing after electron exposure has been conducted for two composite materials: T300/5208, a graphite/epoxy, and C6000/PMR15, a graphite/polyimide. For graphite/epoxy the strength and modulus increased for total doses up to $2.5(10)^8$ rads. Similar increases for other materials have been attributed to cross coupling. Above $2.5(10)^8$ rads, the increase diminishes possibly due to onset of chain scission. The graphite/polyimide composite showed more radiation resistance. The changes in flexural properties following gamma exposure have the same trend with respect to total dose. However, the peak increase occurs at a lower dose. The study will continue with measurements of changes in flexural properties for larger radiation doses, similar to that expected for 20-30 years of space exposure at GEO.

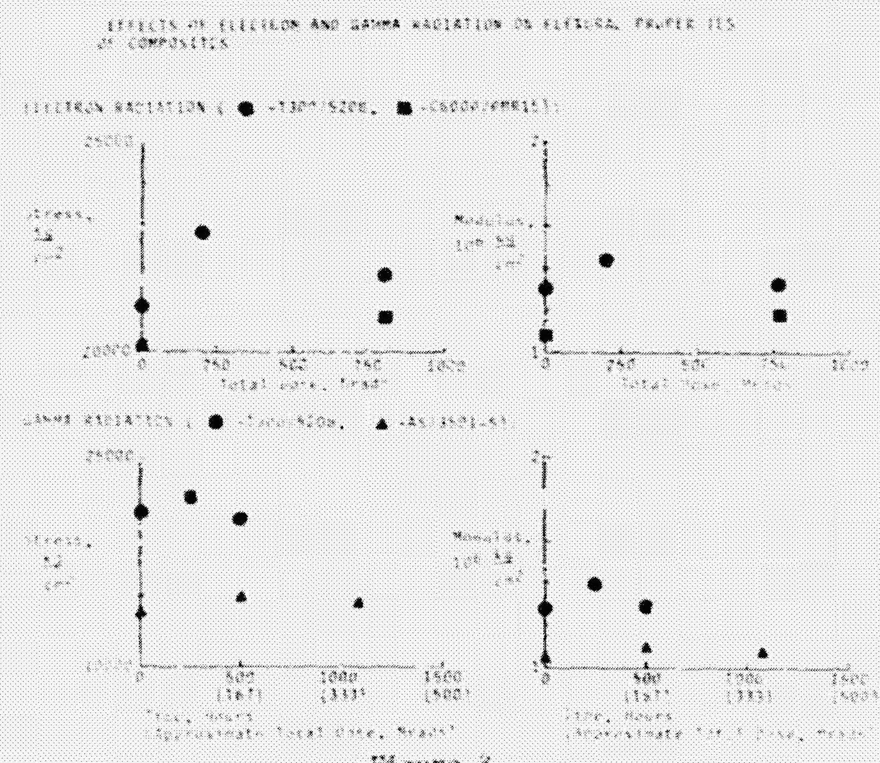


Figure 8

DECREASE IN OPTICAL TRANSMISSION OF H-FILM AFTER AN ABSORBED ELECTRON DOSE OF 10^9 RADS

Measurements of changes in the optical transmission of polymer films due to ionizing radiation is a method for measuring the degradation due to absorbed dose. Measurements are made in the visible region to detect creation of molecular complexes analogous to color-centers in solid state physics. The measurements in the UV region show molecular energy level changes because UV energy excites the electrons in molecular orbitals to higher energy states. Changes in optical transmission due to electron and proton radiation may also indicate differences in the two forms of radiation. Finally the measurements may also be important for detection of combined UV and ionizing radiation synergistic effects. The transmission spectra for electron irradiated H-film were taken on a Cary-14 spectrometer. The spectra show tha. permanent molecular structure change has occurred because the absorption of UV has almost doubled.

DECREASE IN OPTICAL TRANSMISSION OF H-FILM AFTER AN ABSORBED ELECTRON DOSE OF 10^9 RADS

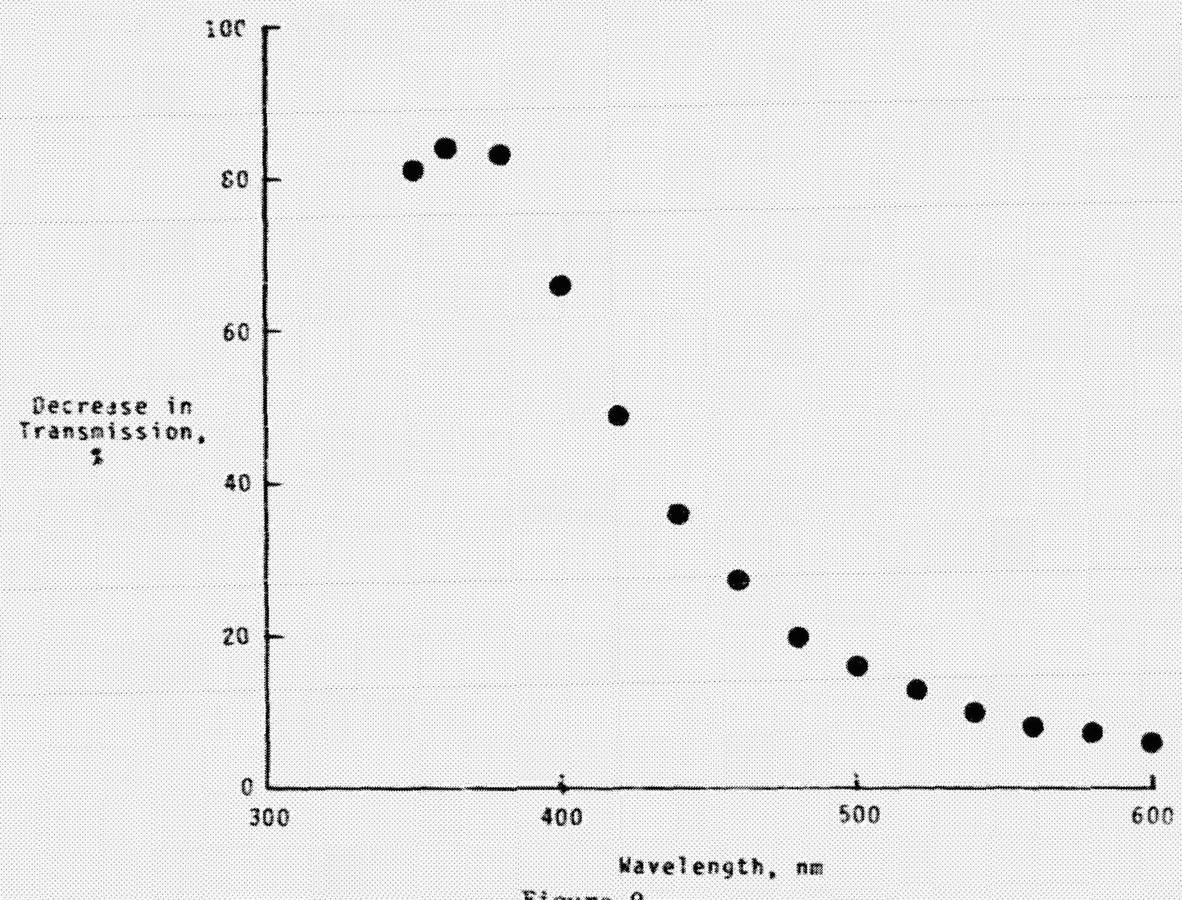


Figure 9

EFFECTS OF ELECTRON RADIATION ON H-FILM AS DETERMINED BY INFRARED SPECTROSCOPY

Infrared (IR) spectroscopy measures a materials transmission or reflection of electromagnetic radiation wavelength from approximately 2 to 25 microns. This range of wavelengths corresponds to the energies required to cause molecular bonds to vibrate. Therefore, the variation in transmission (absorption) of the IR radiation with respect to IR wavelength is a description of the bonds within the molecular structure. The IR spectra shown below are for an H-film. The spectra are shown for before, at the tail end of, and five minutes after a 6 KeV electron dose of 10^{10} rads. The bonds responsible for the spectra are identified. An example molecular structure for H-film is given which shows where such bonds occur. The spectra show that transmission increased when the polymer film was irradiated with electrons and continued to increase after electron radiation. An interpretation of the increase is that the number of bonds have decreased, that is the molecular structure has been damaged. In particular, the number of aromatic ether bonds, C-O-C, is the most affected. Thus this bond may be the weakest link in the backbone of the polymer chain. A portion of spectra is shown in the lower right for a 10^9 rad dose. The spectrum for after radiation appears to have nearly returned to preradiation conditions. Recovery after a 10^9 rad radiation dose has also been observed for mechanical properties of the film. The two forms of observed recovery may correspond to one another. If so, then permanent changes in mechanical properties may occur for doses larger than 10^9 rads where the IR spectra were permanently altered.

EFFECTS OF ELECTRON RADIATION ON H-FILM AS DETERMINED BY INFRARED SPECTROSCOPY

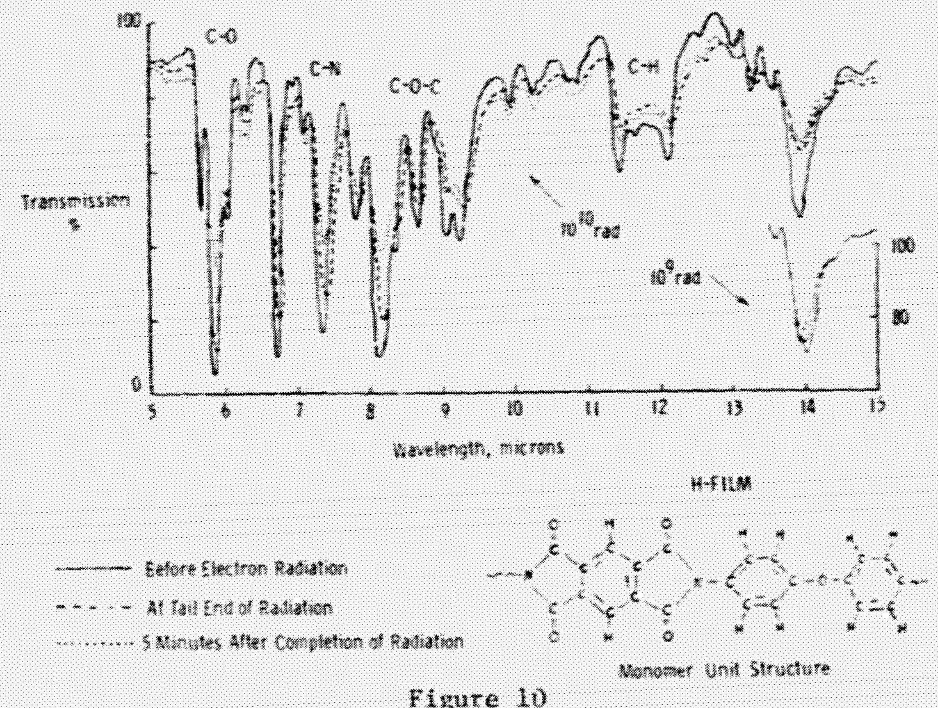


Figure 10

RADIATION EXPOSURE OF COMPOSITE MATERIALS

The objective of this research is to provide simulated space radiation exposure of a variety of laminated graphite fiber reinforced polymeric matrix composites. The effects of radiation on the mechanical, chemical and physical properties will be evaluated to assess the space durability of these materials and to determine if synergistic radiation effects are significant for composites. The radiation exposure program includes both individual, simultaneous and sequential exposure to 300 KeV electrons and/or 2.0 MeV protons with fluences to 2×10^9 rads (absorbed dose) at specimen temperatures of 25°C and 120°C. These data will be used to determine whether radiation damage due to simultaneous electron and proton exposure is greater than due to sequential electron and proton exposure. Synergism has been verified in the optical properties of thermal control coatings but no data could be found in the literature for mechanical and physical properties of composites.

RADIATION EXPOSURE OF COMPOSITE MATERIALS

OBJECTIVE: TO PROVIDE RADIATION EXPOSURES OF COMPOSITE MATERIALS FOR EVALUATION OF SPACE RADIATION EFFECTS ON MECHANICAL, CHEMICAL & PHYSICAL PROPERTIES

CAPABILITIES: 250-300 KeV e^-; 2.2 MeV p^+; $e^- + p^+$;
$p^+ \rightarrow e^-$; $e^- \rightarrow p^+$; BEAM AREA - 20 cm. Dia.;
FLUX TO: 5×10^{11} e^-/cm^2-sec or p^+/cm^2-sec

TESTING PROGRAM	MATERIAL SYSTEMS
EFFECTS OF:	T300/934
TYPE OF RADIATION	T300/5208
SINGLE, COMBINED AND SEQUENTIAL EXPOSURES	T300/POLYSULFONE
TOTAL DOSE	CELION 6000/PMR15
DOSE RATE	GY-70/E793
SPECIMEN TEMPERATURE	GY-70/7740 GLASS
LOAD ON SPECIMEN	NEAT RESINS

Figure 11

RADIATION EXPOSURE TEST METHODOLOGY

The objective of this research program is to evaluate the effects of 1.0 MeV electrons on composite materials in-situ, in-air and in-vacuum to determine the effects of post exposure test conditions and to evaluate the effect of continuous versus interrupted radiation exposure on the degradation of composites. A series of approximately 10 exposures of 3 composites (18 specimens/exposure) to 2×10^9 rads of 800 KeV electrons will be conducted with substrate temperatures of 25°C and 120°C. The post irradiation tests will be conducted in-situ (during irradiation), in-vacuum and in dry air to determine if future testing can be conducted in dry air using conventional laboratory mechanical property testing equipment or if these tests will require expensive vacuum test equipment. These data will also evaluate the effects of continuous versus interrupted radiation exposure on the degradation of composites. Part of these exposures will be performed for 8 hours/day over a week and some continuously for 24 hours/day for the same total hours.

RADIATION EXPOSURE TEST METHODOLOGY

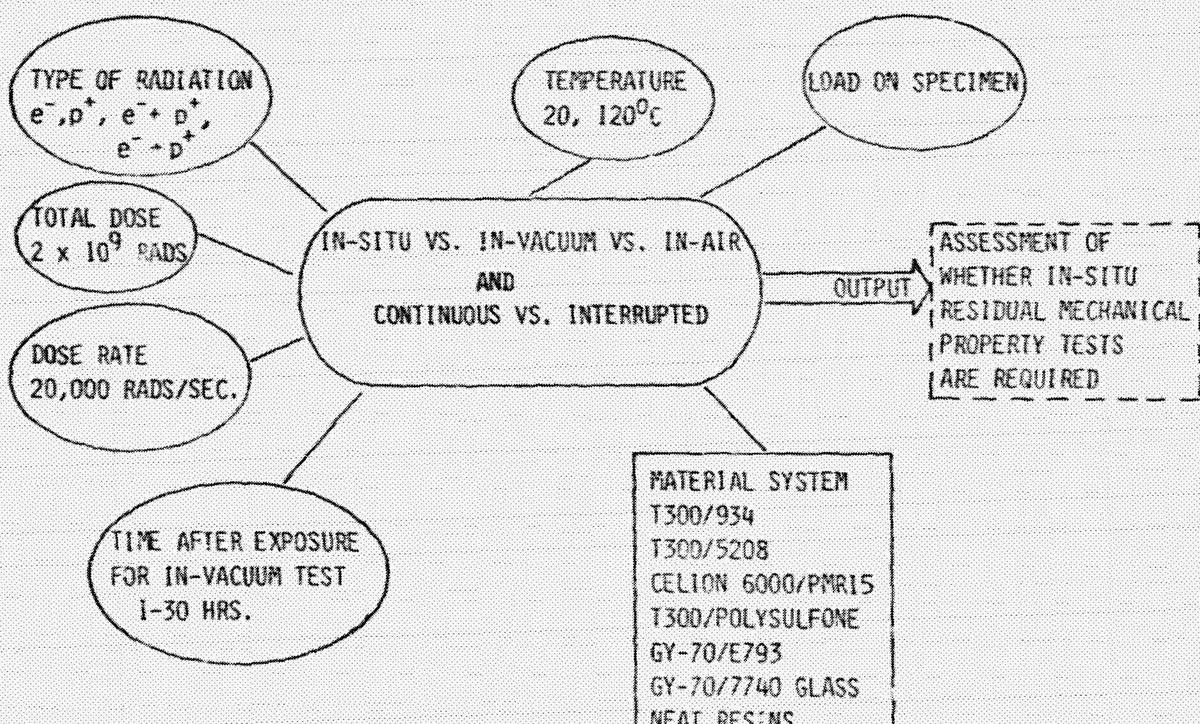


Figure 12

INVESTIGATION OF DEGRADATION MECHANISMS IN COMPOSITE MATRICES

The objectives of this program are: (1) to establish the mechanisms of degradation for composite matrices and to provide data to predict the long-term durability of composites in geosynchronous orbit; (2) to establish the feasibility of using current low α_s/ϵ thermal control paints for UV protection of composites.

One technique used to establish the damage mechanism is to collect the gas given off during irradiation, analyze both the condensible and non-condensible constituents in this gas and relate this to the known polymer compound. This is being performed on films of the composite matrix material and the composites.

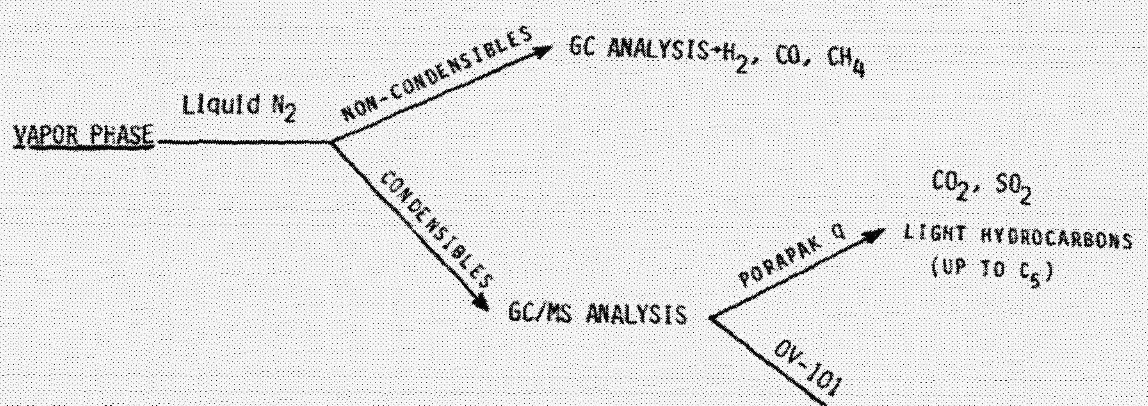
Other tests to be conducted include: ultimate flexure, tension and compression strengths; dynamic mechanical analysis (modulus); electron microscopy surface studies, and other tests to determine the extent of crosslinking where applicable.

INVESTIGATION OF DEGRADATION MECHANISMS IN COMPOSITE MATRICES

PROGRAM SCOPE:

- o TASK I - ESTABLISH THE MECHANISMS OF DEGRADATION AND PREDICT THE LONG-TERM DURABILITY OF COMPOSITES IN GEOSYNCHRONOUS ORBIT
- o TASK II - ESTABLISH THE FEASIBILITY OF USING CURRENT LOW α_s/ϵ THERMAL CONTROL COATINGS FOR UV PROTECTION OF COMPOSITES

TESTING PROGRAM



COMPOSITE SAMPLE:

MECHANICAL PROPERTIES (FLEXURAL, COMPRESSION)
DYNAMIC MECHANICAL ANALYSIS (DMA)
SURFACE STUDIES (ELECTRON MICROSCOPY)
GEL FORMATION AND SOLUTION VISCOSITY (IF APPLICABLE)
GEL PERMEATION CHROMATOGRAPHY (IF APPLICABLE)

Figure 13

A1100 SILANE PRIMED S13G/LO COATED COMPOSITE ADHESION TEST

Thermal control coatings will be required to minimize the temperature variation in large space structures and thus limit the thermal expansion of these structures. Part of the study of coating application to composites was to evaluate primers which would promote adhesion to composites without requiring abrasion of the composite surface. A group of primers was experimentally evaluated and the A1100 primer proved to be the best for all types of composites. This primer was subsequently evaluated using abraded and non-abraded composites and the results are shown in this figure. The non-abraded surface performed as well as the abraded surface in each adhesion test. This significantly reduces the time and cost of application of white paints to composites.

The effect of coating thickness on solar absorptance was also evaluated for S13G/LO applied to a selected group of graphite reinforced resin matrix composites including epoxy, polysulfone and polyimide resins. As the thickness increased from 3 mils to 10 mils, the solar absorptance decreased from approximately 0.29 to 0.18. This demonstrated that a low solar absorptance can be obtained with typical white paints over graphite reinforced composites.

A1100 SILANE PRIMED S13G/LO COATED COMPOSITE ADHESION TEST
(ABRADED SURFACE VS. NONABRADED SURFACE)

SUBSTRATE*	COATING THICKNESS (IN.)	LIQUID N_2 TEST (72 HR CURE)	KNIFE TEST 72 HR CURE	KNIFE TEST 264 HR CURE
5208/T300	A)0.007	PASS	GOOD	GOOD
	B)0.008	PASS	GOOD	GOOD
3501-6/AS	A)0.008	PASS	GOOD	GOOD
	B)0.007	PASS	GOOD	GOOD
P1700/ CELION 6000	A)0.008	PASS	FAIR	FAIR
	B)0.010	PASS	FAIR	FAIR
PMR-15 CELION 6000	A)0.006	PASS	GOOD	GOOD
	B)0.007	PASS	GOOD	GOOD

*A) ABRADED SURFACE
B) NONABRADED SURFACE

ABRADING SURFACE DOES NOT APPEAR TO ENHANCE COATING ADHESION. SOLVENT CLEANING APPEARS ADEQUATE.

Figure 14

DIMENSIONAL STABILITY OF STRUCTURAL COMPOSITES

The performance characteristics of many of the proposed space communication antennas and space-based laser systems are dependent on the dimensional stability of the supporting structure. For these applications, the thermal properties of the materials should include: high thermal conductivity (K_t), high specific heat (C_p), and low coefficient of thermal expansion. These parameters are important because thermal cycling is one of the principal design considerations in development of good dimensional stability. The cycling results from shadowing of structural elements by other structural elements, from orbital movement from sunlight to earth shadow, and for some applications from electrical power heating.

Thermal cycling must be controlled so that total system deflections and thermal loads can be minimized. From a material point of view, thermal cycling control can be accomplished by two basic methods: (1) selecting a material system with a low or near zero coefficient of thermal expansion (CTE), (2) controlling the delta temperature through application of materials coatings or through careful surface preparation such as polishing.

Langley's program in this area is basically directed at analytical calculation and measurement of coefficients of thermal expansion of resin matrix composite laminates and the effect of thermal cycling on CTE. Thermal cycling is known to affect the CTE of certain composite laminates presumably because of microscopic damage to the composite. Also measurements made on small specimens have not always agreed with measurements made on much longer structural elements. These factors will be investigated in this program.

DIMENSIONAL STABILITY OF STRUCTURAL COMPOSITES

OBJECTIVE: DEVELOP ANALYTICAL AND EXPERIMENTAL TECHNIQUES TO ACCURATELY PREDICT THE DIMENSIONAL STABILITY OF LOW CTE STRUCTURAL COMPOSITES SUBJECTED TO THE SPACE ENVIRONMENT.

APPROACH: RESEARCH PROGRAM WILL BE A JOINT IN-HOUSE AND GRANT ACTIVITY WITH THE PRINCIPAL THRUST DIRECTED AT DETERMINING THE CHANGES IN CTE OF COMPOSITES DUE TO ENVIRONMENT EFFECTS.

- o ENVIRONMENTAL VARIABLES TO BE STUDIED
  - o TEMPERATURE
  - o THERMAL CYCLING
  - o LOAD
  - o PARTICULATE RADIATION
- o MEASUREMENT TECHNIQUES
  - o LASER INTERFEROMETER
  - o SIMULTANEOUS LASER INTERFEROMETER AND STRAIN GAGE MEASUREMENTS TO ASSESS ACCURACY OF LITERATURE DATA
- o CORRELATE ANALYTICAL PREDICTIONS WITH EXPERIMENTAL DATA

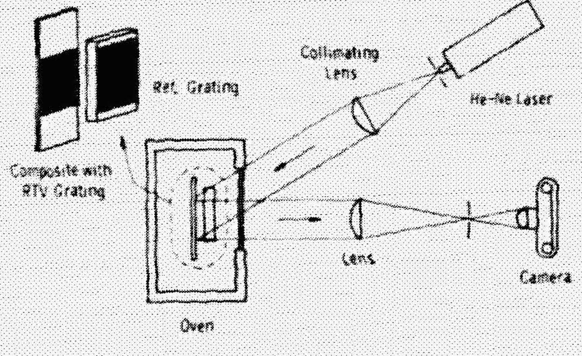
Figure 15

PRECISION MEASUREMENT OF THERMAL EXPANSION OF COMPOSITES

Moiré interferometry was selected as the measurement technique for CTE of composites for the reasons listed in figure 16. Moiré interferometry as described here differs from that of classical Moiré strain measurement techniques in that a fringe multiplication technique is employed. This allows a relatively coarse phase grating to be applied to the specimen while utilizing the resolution capabilities of a much finer reference grating. For this study a reference grating with 1200 lines/mm (30,000 lines/in) on a fused silica blank was purchased from Bausch & Lomb. An RTV silicon rubber phase grating is replicated onto the specimen surface using a 600 line/mm (15,000 lines/in) phase grating on a photographic glass plate. The specimen grating is approximately 0.025 mm thick and the ratio of Young's modulus of the grating to that of the composite is 10^{-3} to 10^{-4}; thus any reinforcement effect is considered negligible. The specimen is mounted in an environmental chamber capable of cycling between +180°C and -150°C. A five milliwatt He-Ne laser is used to illuminate the specimen. Measurements are made by counting fringes between two gage marks cast in the grating, giving a strain resolution of five microstrain.

PRECISION MEASUREMENT OF THERMAL EXPANSION OF COMPOSITES

Moiré Interferometry



Advantages

- PURELY GEOMETRICAL MEASUREMENT OF SURFACE DISPLACEMENTS
- RESOLUTION IS ADJUSTABLE TO FIT THE REQUIREMENTS (RESOLUTION OF 5×10^{-6} WAS SELECTED)
- ELIMINATION OF SPECIMEN END EFFECTS
- FULL FIELD OBSERVATION INCLUDING FREE EDGE EFFECTS
- EASE OF IMPLEMENTATION INCLUDING TEMPERATURE COMPENSATION
- NEGLIGIBLE REINFORCEMENT
- DIRECTLY APPLICABLE FOR MEASUREMENT OF CTE UNDER LOAD
- LOW COST

Figure 16

COEFFICIENT OF EXPANSION AS A FUNCTION OF LAMINATE CONFIGURATION

Laminate analysis is being used to calculate the effect of fiber misorientation and inhomogeneous fiber volume content on the coefficient of thermal expansion of a number of different composite laminates. The above factors can produce unsymmetric laminate configurations which cause a coupling between bending and extensional behavior. This means that surface strains will not be correctly predicted by only a laminate coefficient of expansion, but that a laminate coefficient of curvature must also be used in the prediction. By using laminate analysis, the above factors may be easily and quickly studied to determine their influence. Another improvement that has been incorporated into the laminate analysis is the temperature dependence of the mechanical and thermal properties. This more closely simulates the real material behavior.

COEFFICIENT OF EXPANSION AS A FUNCTION OF LAMINATE CONFIGURATION

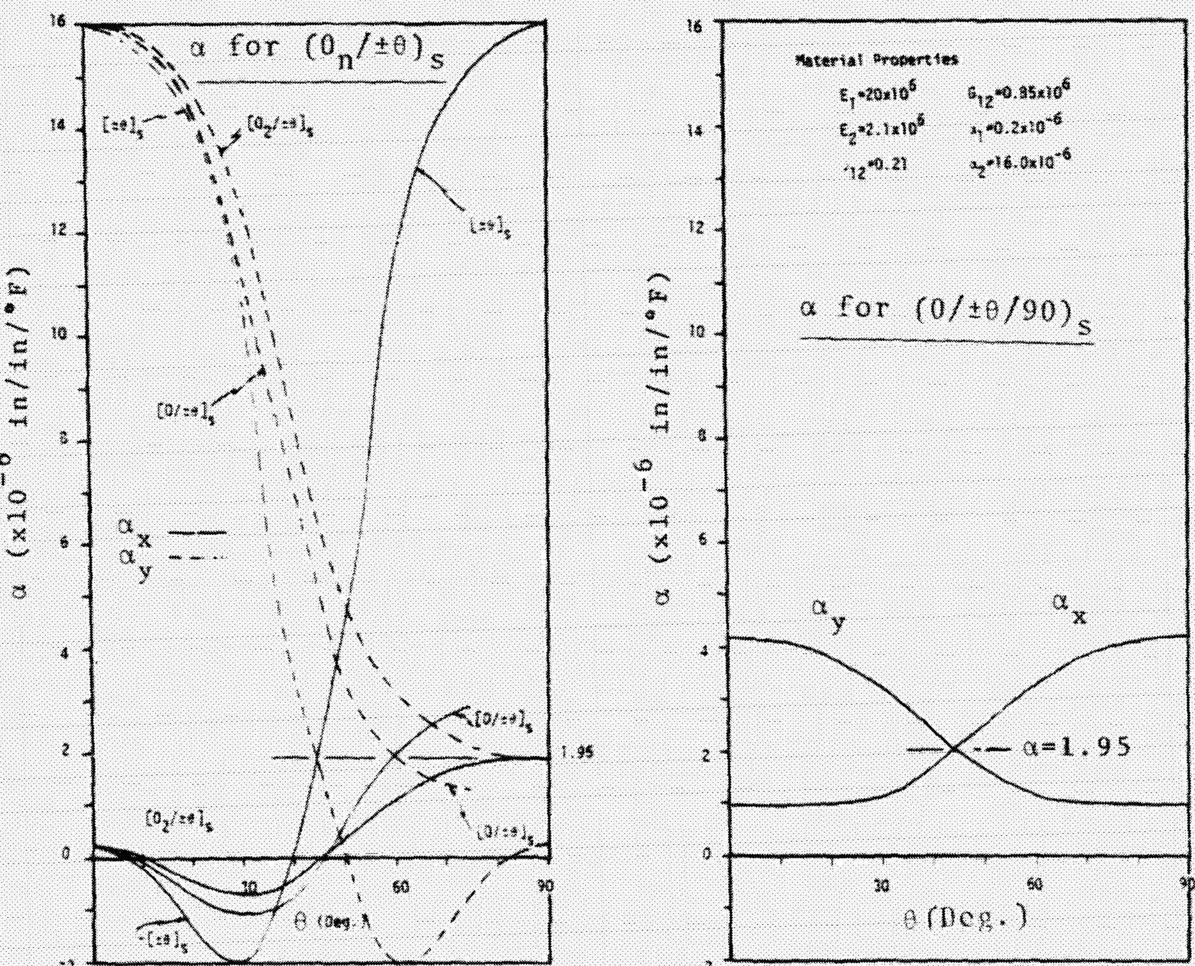


Figure 17

CABLE TECHNOLGOY FOR TENSION STABILIZED STRUCTURES

A common element in many large space structures is the long deployable cable. Many of the advanced concepts for large space antennas are based on tension stabilized structures where the mesh surface of the antenna is maintained to a prescribed shape by tensioning cables. Deployable antenna applications required cables with the following general characteristics: low CTE throughout temperature range; non RF interfering (low loss tangent and dielectric constant); deployable from spool at low temperature extremes; compatible with cable manufacturing equipment; high effective modulus at low prestrains; minimal creep with age and space exposure; high UV resistance; stable upon moisture dry-out, minimal hysteresis; and non self-abrasive. Quartz historically has been the most successful material for deployable antenna applications and will be the prime candidate for new antennas. However, high modulus graphite fibers will be seriously considered for all future applications particularly where RF interference is not a prime requirement.

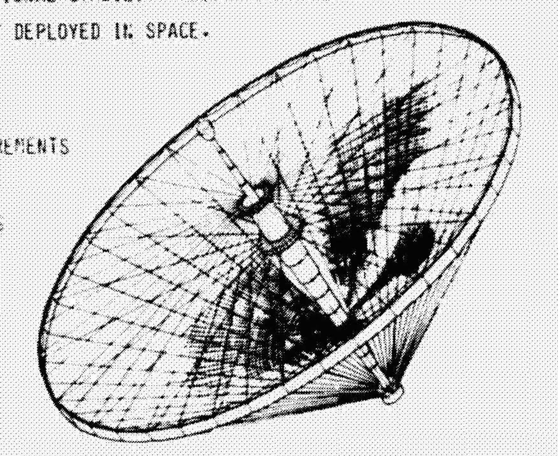
The objective of this effort is to design and develop cable technology for multiple use requirements in antennas or other tension stabilized structures. A variety of cable fibers, both quartz and graphite, and constructions will be investigated in this study. Cables will be manufactured and tested to determine their mechanical and physical properties, effect of space environment on these cables, and ability of these cables to be spooled and deployed.

CABLE TECHNOLOGY FOR TENSION STABILIZED STRUCTURES

OBJECTIVE: DEVELOP MINIMUM WEIGHT AND SIZE CABLES WITH HIGH STIFFNESS, STRENGTH, AND DIMENSIONAL STABILITY WHICH CAN BE TIGHTLY PACKAGED AND READILY DEPLOYED IN SPACE.

CONTRACTOR MATERIALS ACTIVITIES

- DEFINE ANTENNA CABLE REQUIREMENTS
  - o STRENGTH, STIFFNESS
  - o CTE, CREEP, HYSTERESIS
- PACKAGING AND DEPLOYMENT
  - o SPOOLING, JACKETING
  - o CABLE SELF-ABRASION
- RF INTERFERENCE



IN-HOUSE MATERIALS ACTIVITIES

- COMBINED LOAD/VACUUM/UV RADIATION TESTS ON KEVLAR
- COMBINED VACUUM/THERMAL CYCLING TESTS FOR CABLE STRUCTURAL CREEP
- THERMAL CYCLING AND TESTING OF CABLE FASTENERS

CANDIDATE MATERIALS: QUARTZ, GRAPHITE, KEVLAR

Figure 18

SUMMARY OF FY-79 LSST MATERIALS PROGRAM

NASA has identified numerous concepts for large space systems; communications and power transmission antennas and platforms for scientific experiments are of current interest. Advanced filamentary composite materials have the potential of providing extremely lightweight structures for these applications. There are, however, a number of technology needs associated with the long term use of organic matrix composites in the space environment. During FY-79 the LSST materials program has addressed various aspects of most of the material technology needs identified. Because the long-term durability of composites in the space environment is a particularly long lead time area most of the FY-79 resources were used to initiate programs to obtain an early assessment of the space durability of composites to scope the magnitude of the problem and to assist in the planning of a base R&T program to work this area.

Programs were also undertaken to improve thermal control coating technology for composites, measurement of thermal expansion of composites, and development of high strength lightweight cables for tension stabilized structures. During FY-80 the LSST materials program will be focused to address cable technology and dimensional stability of composites.

SUMMARY OF FY-79 LSST MATERIALS PROGRAM

- o RADIATION EXPOSURES OF RESIN MATRIX COMPOSITES UNDERWAY ON CONTRACT AND IN-HOUSE
- o DOSE/DEPTH PROFILE CALCULATIONS FOR ELECTRONS AND PROTONS IN COMPOSITES UNDERWAY
- o LOW ENERGY e^- AND HIGH ENERGY p+ COMPARATIVE STUDY UNDERWAY
- o WHITE PAINT THERMAL CONTROL COATINGS SUCCESSFULLY APPLIED TO COMPOSITES
- o MOIRÉ INTERFEROMETER SYSTEM DESIGNED TO MEASURE CTE OF LOW EXPANSION COMPOSITES
- o HIGH STRENGTH, DIMENSIONALLY STABLE CABLES UNDER DEVELOPMENT FOR TENSION STABILIZED STRUCTURES

Figure 19